Methanol: a diagnostic tool for high-mass star-forming regions

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1 Introduction

Kinetic temperature and density are fundamental parameters for our understanding of the interstellar medium (ISM). Usually, symmetric rotors such as NH_3 are used to probe a cloud's kinetic temperature, while linear molecules, e.g. CS, probe its density. However, different spatial distributions of the tracers ("chemistry") often complicate the picture (see, e.g., [8]) as they often trace physically different and spatially non-coexisting gas components. It is thus desirable to trace all relevant physical parameters with a single molecule. Promising candidates exist among slightly asymmetric rotors, which have properties qualifying them as tracers for physical conditions. Methanol, CH_3OH, is a slightly asymmetric rotor. It is ubiquitous and associated with different regimes of star formation, from quiescent, cold (T $\sim$ 10 K), dark clouds, to "hot core" sources near high-mass (proto)stellar objects, where $[CH_3OH/H_2]$ values $\sim 10^{-7} - 10^{-6}$ are observed [3]. Up to now an extremely poor knowledge of the CH_3OH collisional rates and of their propensity rules has prevented realistic systematic studies exploiting methanol's full potential as an interstellar tracer. Recently, this situation has changed with the calculation of collisional rate coefficients by [5, 6], for collisions with helium, for both CH_3OH-A and CH_3OH-E, for levels up to $(J, K) = 9$.
Here we would like to focus on general aspects connected to the analysis of complex molecules' spectra, of which CH_3OH is one of the simplest examples, (for details on methanol excitation and on its probing properties see [2]).

2 Analysis technique

The traditional approach for deriving physical parameters such as kinetic temperature and spatial density from an observed spectrum involves "by-hand" fitting of the lines with multiple components and χ^2 analysis comparing the measured quantities with statistical equilibrium calculations. However, this single line fitting procedure is extremely time-consuming and suf-

fers from several drawbacks. With sensitive receivers nowadays available and in view of the next generation of instruments, which will provide copious amounts of data in a short time, new methods of data analysig and modelling are required.

An innovative technique to handle the problem, proposed by [7] and recently improved by [1], is based on the simultaneous fit of the complete spectrum with a synthetic spectrum computed under Local Thermodynamic Equilibrium (LTE) conditions. Here we propose an extension to this technique using the Large Velocity Gragient (LVG) approximation, which ensures more reliable results when prominent departures from LTE are expected. The free parameters for each component are excitation temperature, molecular hydrogen density, source size, column densities for A and E states, which are treated as two independent parameters to take into account their possibly different abundance. Line width and LSR velocity are fixed parameters and assumed to be the same for all the lines in each component. Within a component, the optical depths for lines with a frequency separation $\nu_i - \nu_j \leq \Delta\nu_i + \Delta\nu_j$ are summed up to include local line overlap between both symmetry states. Line identification is based on the Cologne Database for Molecular Spectroscopy, (http://www.cdms.de [4]), which includes new measurements by [9].

Although the simultaneous fit of a spectrum has been demonstrated to be a powerful technique of analysis [1], it does imply several approximations. The assumption behind the analysis is that the CH_3OH distribution can be reasonably well approximated by a small number of non-interacting components, thus ignoring any structure in the source. The LVG approach adds other uncertainties to the obtained results, since it assumes only one set of physical parameters for the source and implicitly neglects any local and non-local overlap between the lines. Also, fitting CH_3OH spectra assures a reliable determination of kinetic temperature only when a large amount of lines are fitted and/or when millimeter and submillimeter data are combined, since CH_3OH shows a strong dependence on temperature mainly in the submillimeter range [2]. Another drawback is the uniqueness of the χ^2 minimization, which is not *a priori* guaranteed. Indeed the fit results occasionally depend on the input parameters: an analysis of the χ^2 distribution is therefore necessary to verify that the found minimum is global.

Having all these limitations in mind, the application of this technique to G79.3P1, an infrared-dark cloud, gives very satisfying results, (Fig. 2). Table 1 lists the best fit results and the 3σ fit range. The source size, $32''$, is based on a BIMA map of CH_3OH at 3mm, (Wyrowski, priv. comm.). Fig. 1 shows the χ^2 distribution in the $[T_{kin}, n(H_2)]$ plane, with the 3σ confidence surface in black.

Table 1. CH$_3$OH model results for G79.3P1, $\chi^2_{\nu_d}$=0.7, ν_d=22.

	best fit	3σ fit range
T$_K$	17 K	12–37 K
n(H$_2$)	2.5 10^5(cm^{-3})	3 10^5– 4 10^6(cm^{-3})
N(CH$_3$OH-A)	7.9 10^{13} (cm^{-2})	6 10^{13}–1 10^{14}(cm^{-2})
N(CH$_3$OH-E)	5.7 10^{13} (cm^{-2})	3 10^{13}–8 10^{13}(cm^{-2})
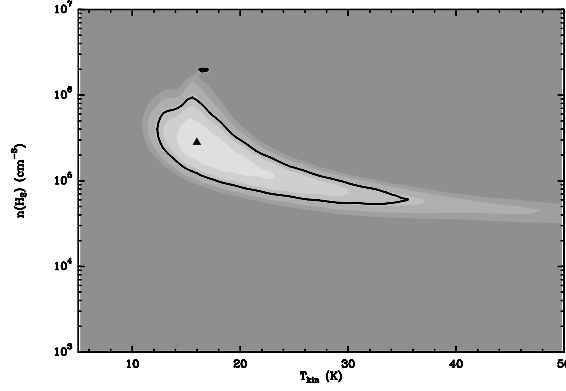
Fig. 1. χ^2 distribution in the [T$_{kin}$,n(H$_2$)] plane, N(CH$_3$OH-A)=7.9 10^{13}, N(CH$_3$OH-E)=5.7 10^{13}, toward G79.3P1. A black triangle marks the minimum position, T$_{kin}$=17 K, n(H$_2$)=2.5 10^5 cm^{-3}; dashed in black the 3σ confidence surface for 22 degrees of freedom.

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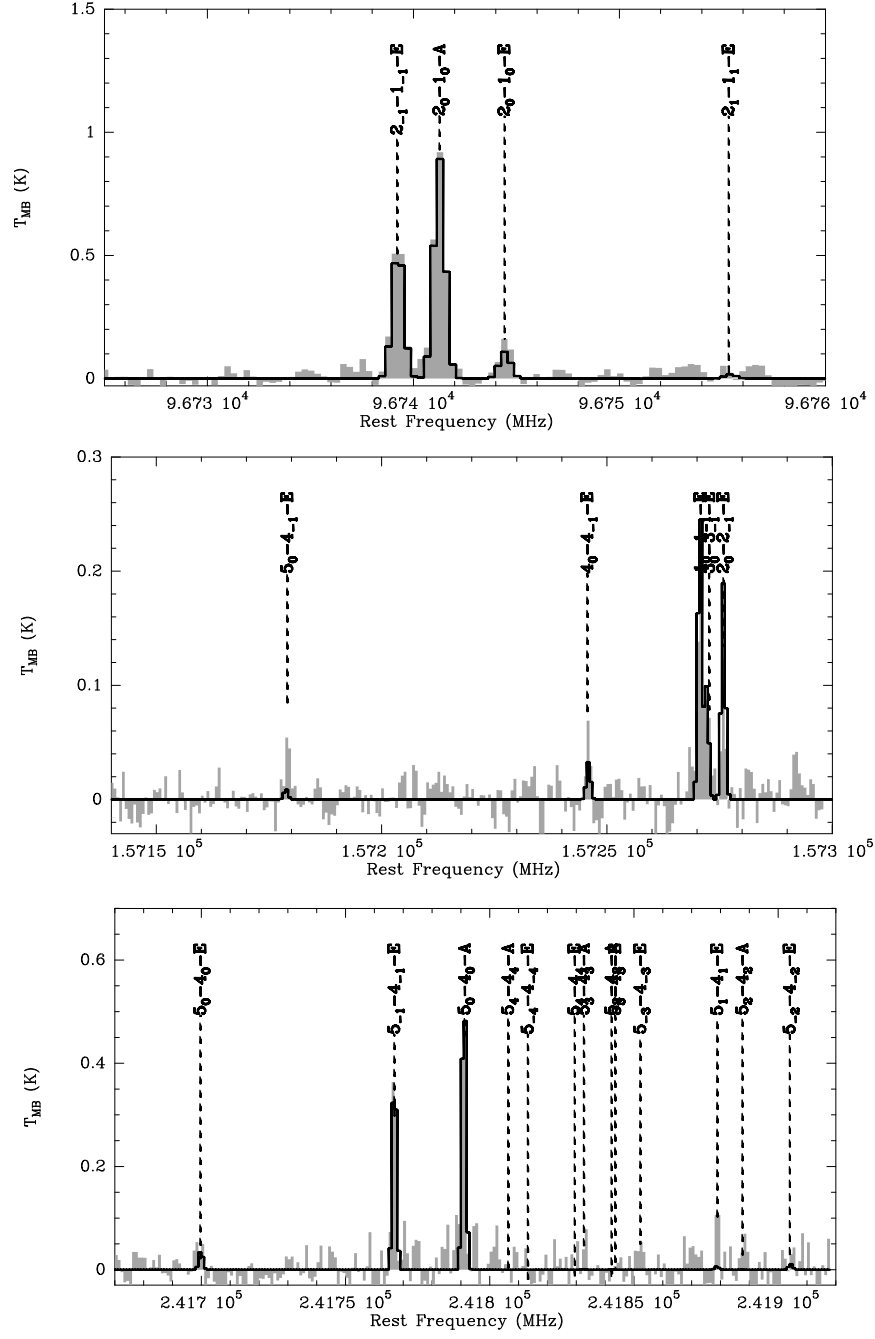9. L.-H Xu and F. L. Lovas: J. Phys. Chem. Ref. Data **26**, 17 (1997)

Fig. 2. CH$_3$OH spectra toward G79.3P1 taken with the IRAM 30m telescope; the 2mm and 1mm data have been smoothed to the 3mm beam size ot the IRAM telescope for comparison with the 3mm data. Labels show all the CH$_3$OH transitions. Overlaid in black the synthetic spectrum resulting from the fit.